SOCIO-ECONOMIC TIPPING POINTS in adaptation to climate change

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TU Delft

European Research Council

Netherlands Organisation for Scientific Research

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Outline

I. What is a tipping point?

II. Tipping points in climate change adaptation

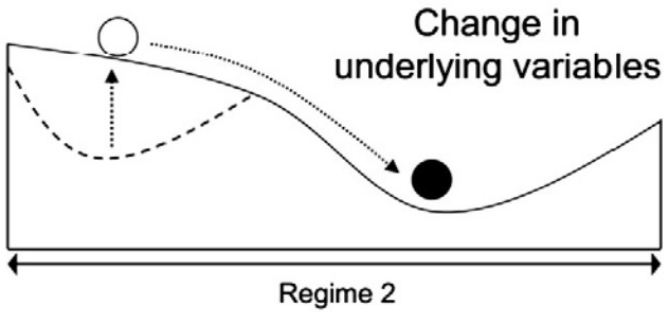
III. Modeling methods to quantify tipping in social-economic systems under climate change:

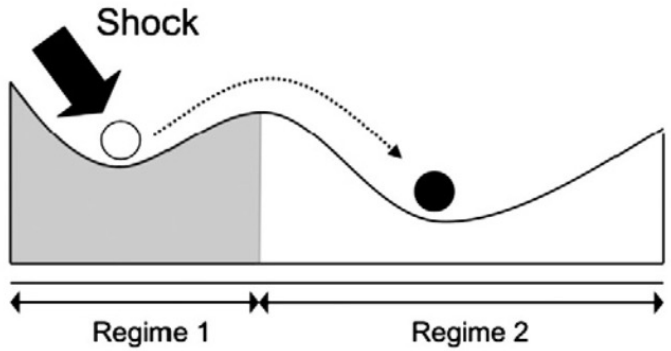
- Example 1: housing markets
- A snapshot on other examples (regional economy & raising tides; social amplification of risks; stranded assets & financial implications)

IV. Closing comments

I. Tipping Points & Climate change

- Ecology / Environmental sciences / Earth systems sciences
  - Generic theoretical foundations, with roots in dynamical systems theory, bifurcations (math), phase transitions (physics)
  - Relates to the ”notion that a steady change in some control parameter… leads to a qualitative change in the system state when some [critical] threshold is passed” Lenton (2013)
  - Types: **(1) bifurcation tipping;** (i.e. the attractor bifurcates, shifts abruptly) **(2) noise-induced tipping…** (internal perturbation causes a shift to another regime)





Source: Crepin et al (2012); Lenton (2013)

nature
International journal of science

Complex systems
Foreseeing tipping points

Marten Scheffer

Nature **467**, 411–412(2010) | Cite this article

PNAS

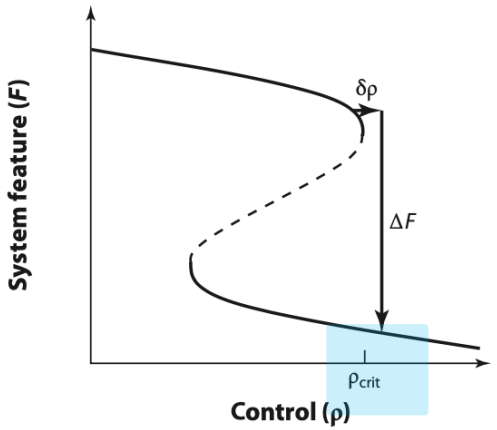
Tipping elements in the Earth's climate system

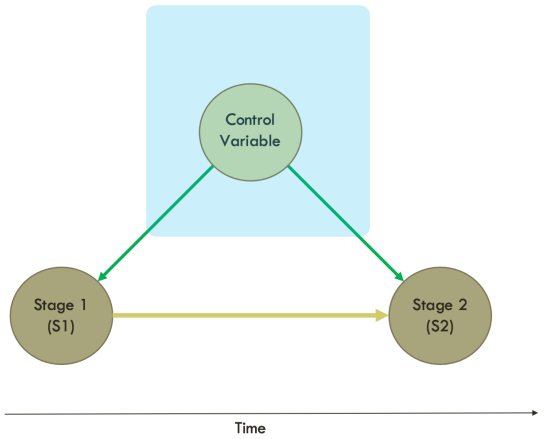
Timothy M. Lenton, Hermann Held, Elmar Kriegler, Jim W. Hall, Wolfgang Lucht, Stefan Rahmstorf, and Hans Joachim Schellnhuber

PNAS February 12, 2008 105 (6) 1786-1793; first published February 7, 2008
https://doi.org/10.1073/pnas.0705414105

I. Tipping Points & Climate change

- Ecology / Environmental sciences / Earth systems sciences
  - Generic theoretical foundations





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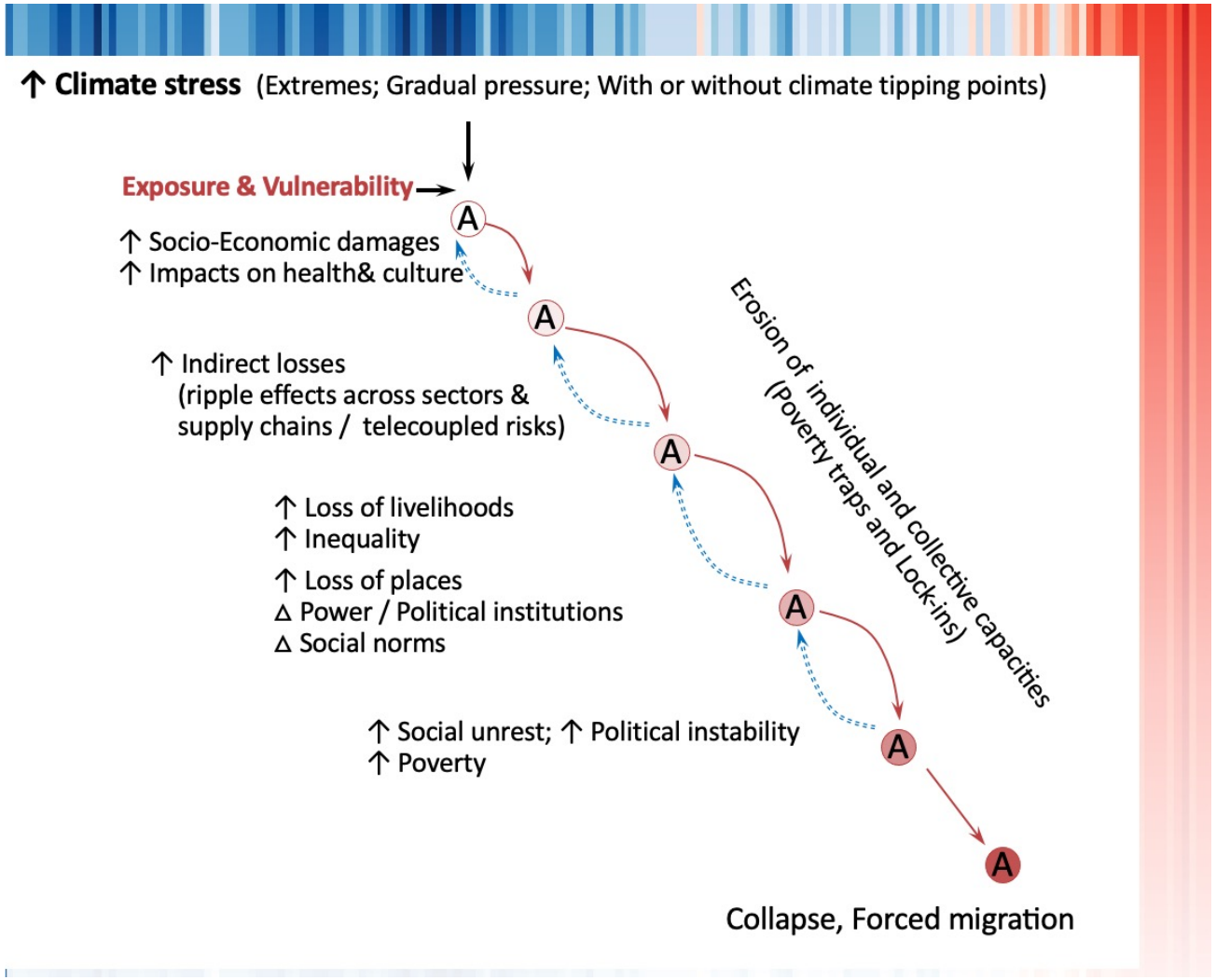
  - Time series data, per **Tipping Element**
  - Mechanisms identified
  - And modelled

  - Conceptualization of tipping in the socio-economic system are in infancy:
    - Aggregated data, a few years of observations
    - Likely no tipping that can be attributed to climate change (yet)
    - Mechanisms barely conceptualized; narratives mainly
    - Hardly any (time series) data on (micro) mechanisms
    - Formal models exist, but mainly outside the CC domain

II. Social Tipping Points in climate change adaptation



Source: Juhola et al (2022) Social tipping points and adaptation limits in the context of systemic risk…, **Frontiers in Climate**

- Disaster alone is insufficient


nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-020-20435-2 OPEN

Exposure to natural hazard events unassociated with policy change for improved disaster risk reduction

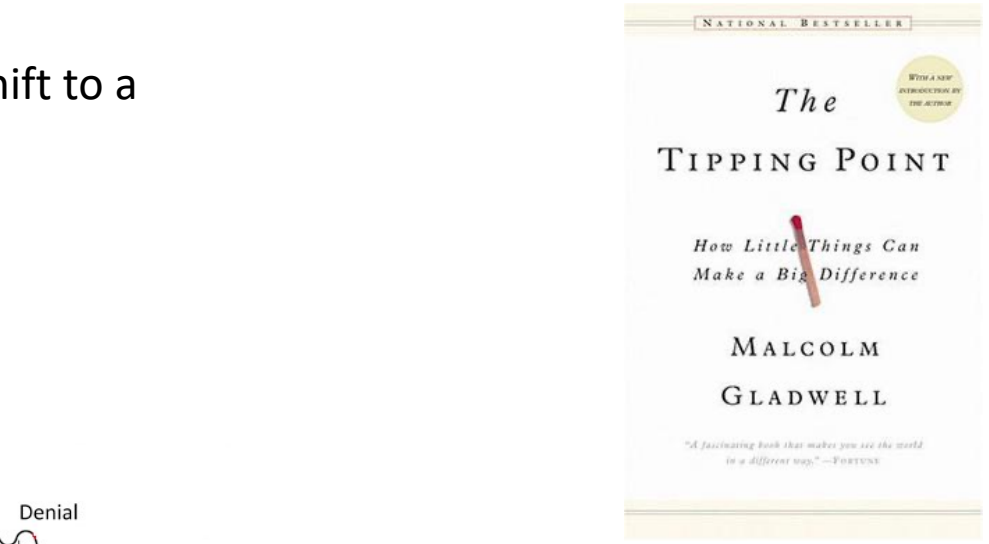
Daniel Nohrstedt[1,2✉], Maurizio Mazzoleni[2,3], Charles F. Parker[1,2] & Giuliano Di Baldassarre[2,3]

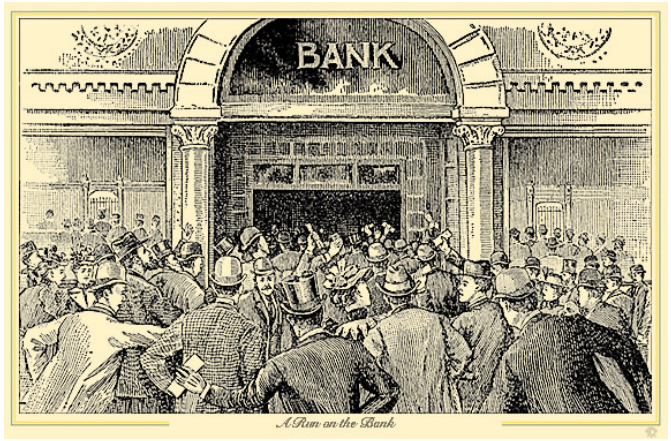
- Cascades / Systemic risks / Domino effect
- In 1 or more socio-economic Tipping Elements
  - On which empirical evidence exists; just not always in relation to CC
  - Models exists to explore the non-linear system dynamics
- Feedbacks
- Distributions of impacts, not averages

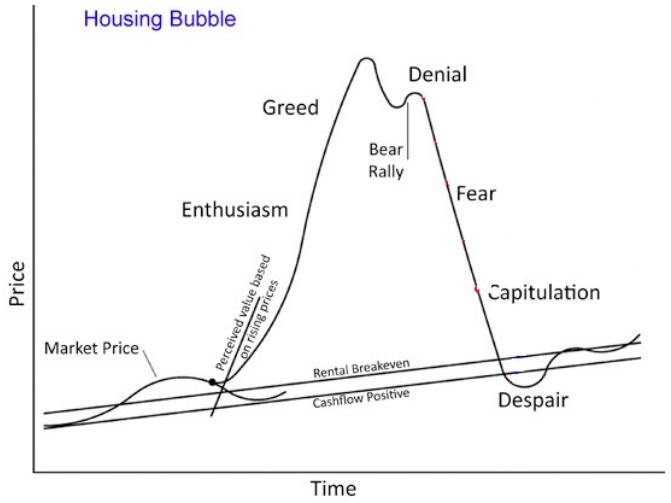
II. Socio-economic tipping points outside CC

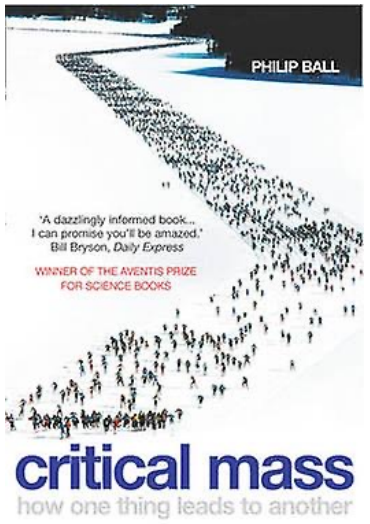
- A threshold at which small change in a driver leads to a runaway process driven by feedbacks, and triggers a drastic irreversible shift to a qualitatively new system state;

Subjective judgements – Contagion (Diffusion) –
Self-reinforcement feedbacks – Rapid acceleration









What are the different tipping elements & corresponding thresholds?

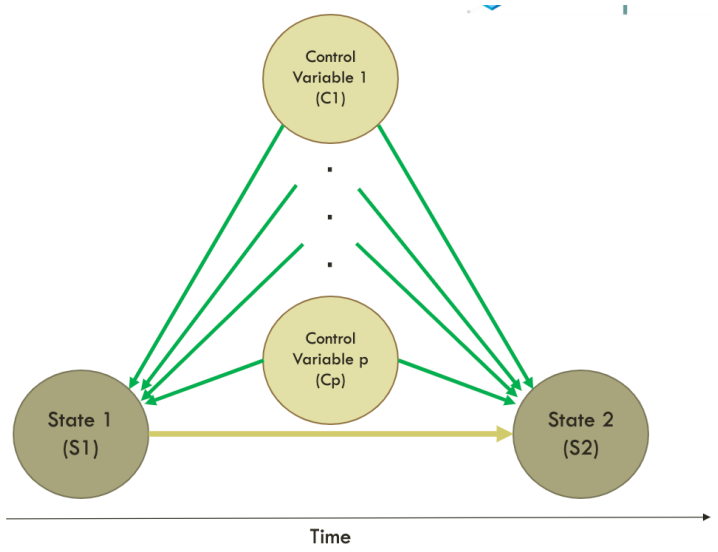
Is there (micro) data?

Can we include those in formal models?

II. Towards identifying mechanisms of tipping

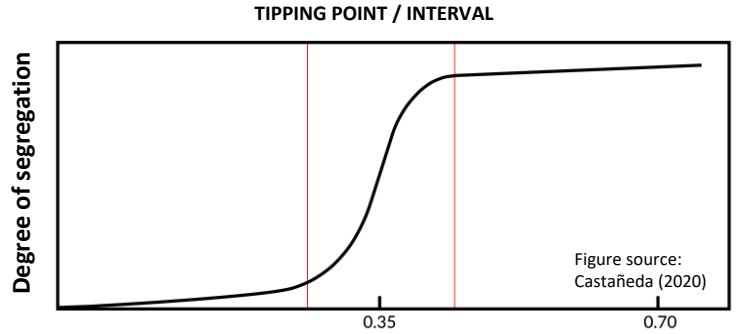
- A threshold at which small change in a driver leads to a runaway process driven by feedbacks, and triggers a drastic irreversible shift to a qualitatively new system state;
- Analysis of tipping processes: macro phenomena as a function of changes in a driving factor

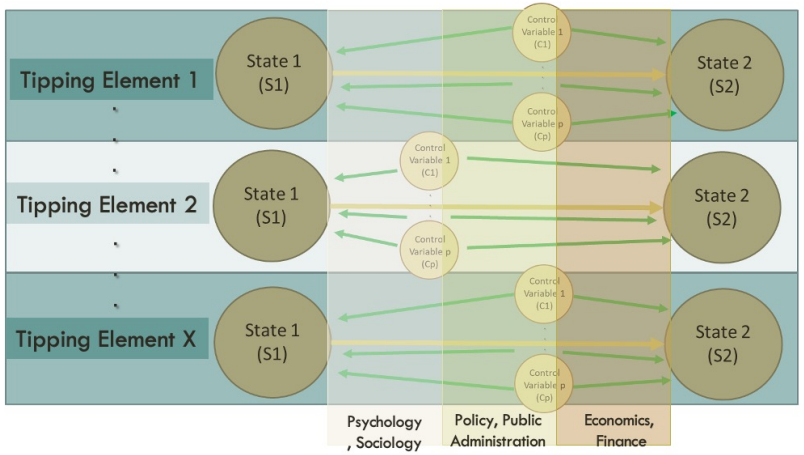
CC: multiple drivers



Source: Gil-Clavel, Filatova (Under submission)

Segregation: T. Schelling (2005 Nobel Prize)



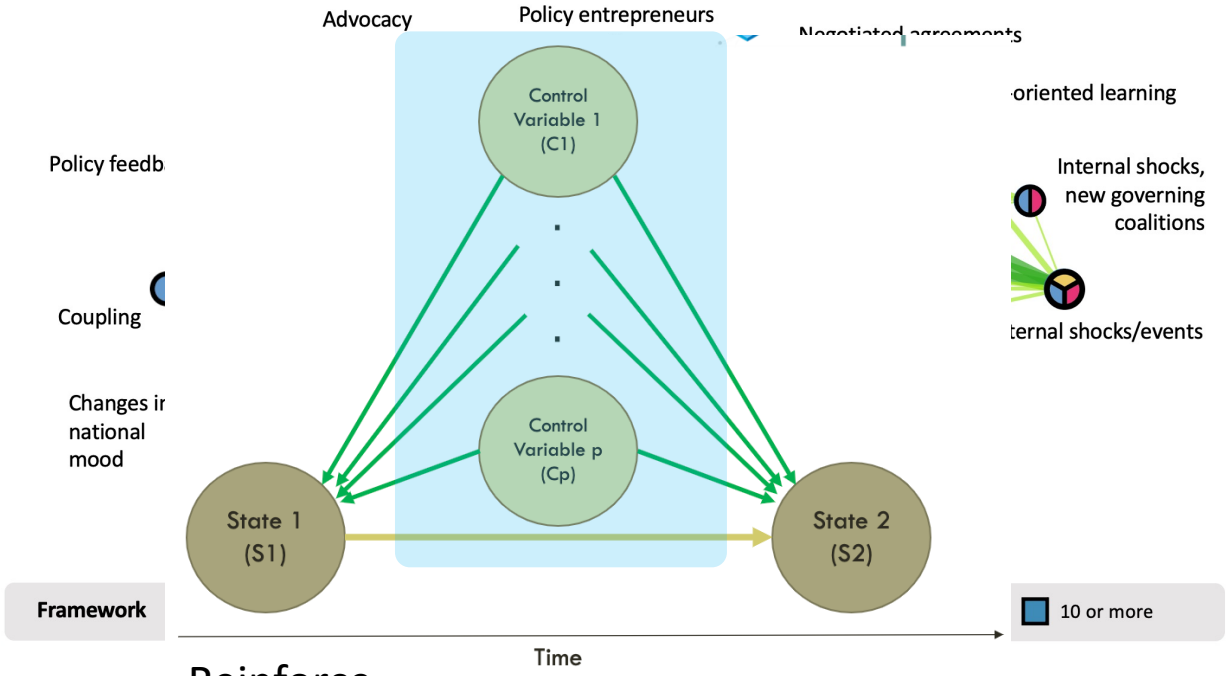


Theory-grounded mechanisms

Qualitative analysis
&
Natural Language Processing

II. Towards identifying mechanisms of tipping

- Qualitative analysis: policy change mechanisms
- Cases: managed retreat & planned relocation (54 articles: 105 cases in 31 countries)
- 3 policy process theories

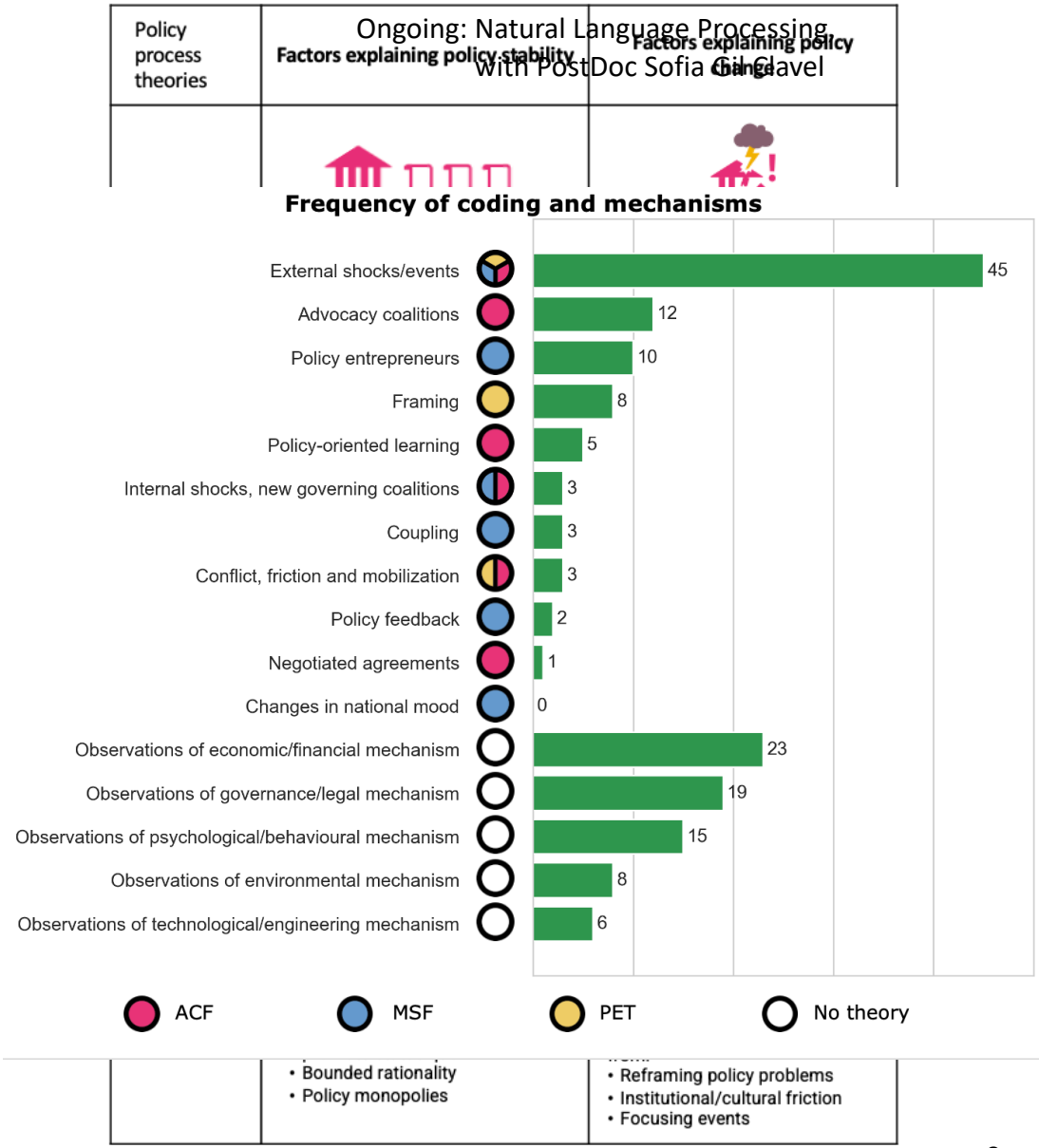


Reinforce flood defenses

Retreat; Relocate

Source: Pot et al (Under review)

Ongoing: Natural Language Processing with PostDoc Sofia Ginglavel



III. Modeling tipping in complex adaptive S-E systems

Progress in the past 10y

Model's ability to incorporate :

1. feedbacks (S ⇔ E, scales)
2. sources of regime shifts
3. complexity (scales, non-linearities, thresholds)
4. regime shift identification

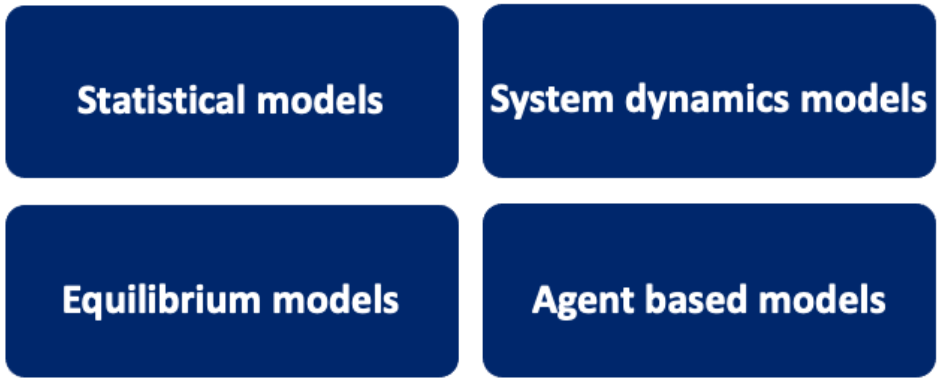


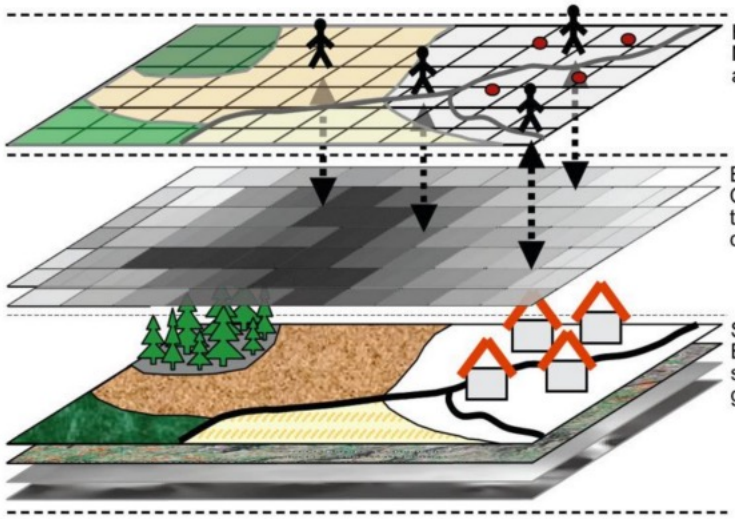
Table 8
Strengths and limitations of various modelling approaches for studying regime shifts. Notation: "√" means that a method can be used if a condition is satisfied, "–" denotes that it is impossible or difficult to apply a method when a condition is present, an empty cell implies neutrality.

Modelling context/conditions	Statistical	SD	EM (non-CGE)	EM (CGE)	ABM
Feedbacks					
one-way linkage	√			√	
chain of links				√	
feedback loops	–	√	√		√
Source of regime shift[a]:					
exogenous pulse disturbance			√	√	√
exogenous press disturbance	√	√	√		√
endogenous gradual change	√	√	√		√
Complexity					
multiple scales (spatial/institutional)	–		–	√	√
nonlinearity		√			√
thresholds	√	√			
Regime shift identification					
detection	√				
temporal scales & reversibility		√	–	–	√
Availability of data					
time-series of aggregated environmental data	√			√	
time-series of aggregated socio-economic data	√			√	–
disaggregated data					√
Treatment of a regime shift:					
test statistical difference between 2 regimes	√	–	–	–	–
reproduce a known regime	√	√	√	√	√
grow a potential regime shift	–	√	√	–	√
a simple comparison of scenarios	–			√	
Relation to stakeholders:					
stakeholders are (or could be) actively involved in modelling	–	√	√	–	√
state institutions issue contract research (macro analysis)	√			√	
Simplification vs. high computing demands:					
simplified assumptions	√	√	√	√	
access to computing power and data analysis methods	√				√
agents adaptive behaviour and learning	–			–	√
heterogeneity	–	–	–	–	√
out-of-equilibrium dynamics and path-dependence		√		–	√
explicit spatial representation		–	–	-	

Source: Filatova et al. (2016) "Regime shifts in coupled socio-environmental systems…", **Environmental Modelling & Software**, 75

III. Agent-based modeling

- Computational agent-based modeling: “a computerized simulation of a number of decision-makers (agents) and institutions, which interact through prescribed rules” (Farmer and Foley, Nature 460, 685–686, 2009)

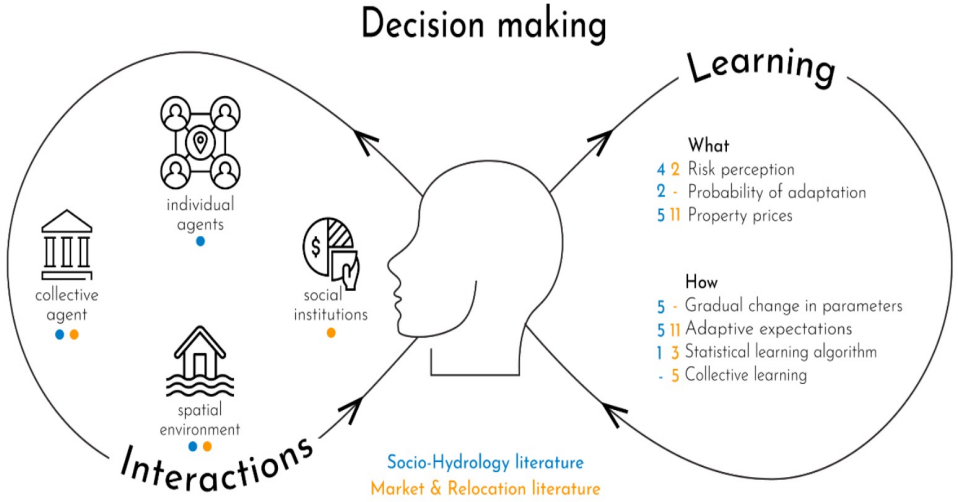


Socio-economic system:
Individual choices, perceptions, learning and adaptation; social interactions; markets and social institutions.

Climate-induced hazards:
Probability and severity of a hazard in each location

Spatial system:
Land use and cencus data

Source: Figure is adapted and modified following Leyk et al (2009)



Source: Taberna et al (2020) ‘Tracing resilience, social dynamics and behavioral change: a review of agent-based flood risk models’, SESMO

III. Individual risk perceptions & market institutions

- Repetitive floods

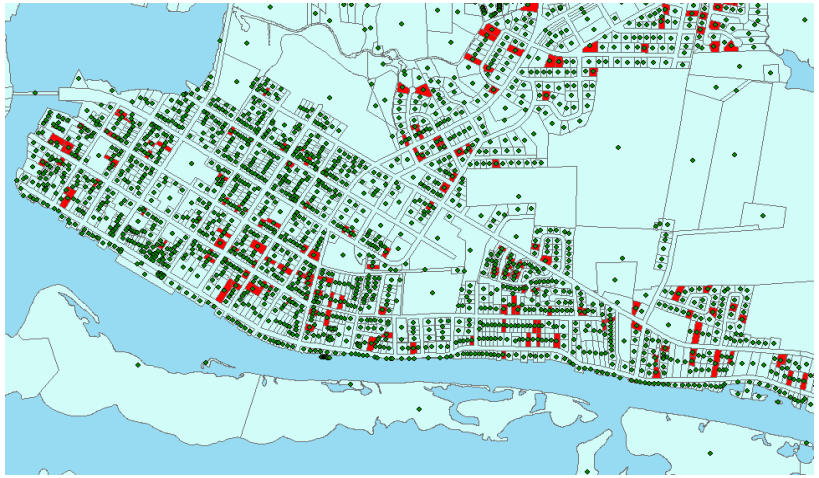
III. Individual risk perceptions & market institutions

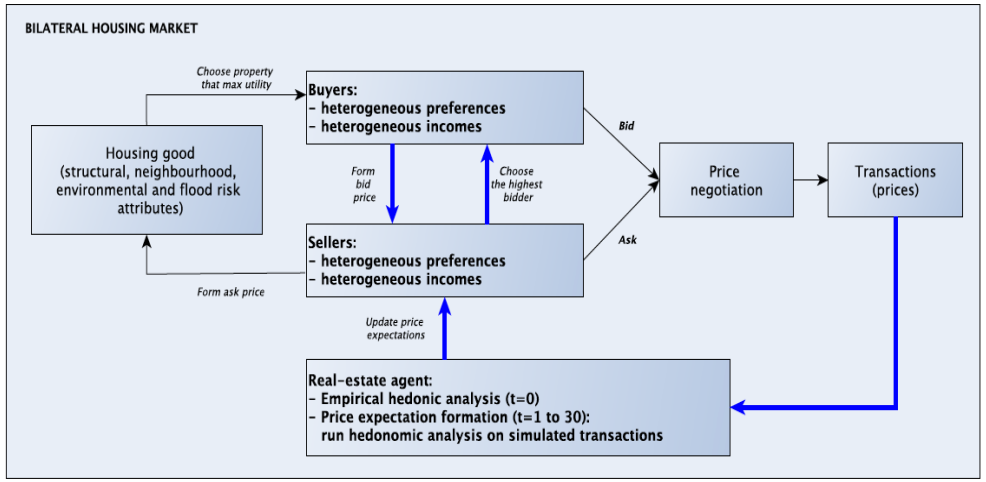
- Repetitive floods
  - Stylized fact 1: **amenities vs. risks**
  - Stylized fact 2: **evolution of risk perception**
    - $P_{hazard} < P_{safe}$ (4-10%)[1]
    - Effect increases after a flood (in 2-3 times)[2]
    - Even if disaster did not hit actually[3]
    - Effect disappears 5-6 years after the event[4]
  - Stylized fact 3: **climate change and urbanization**
    - Non-marginal change (outmigration; sorting)[5]
    - Change of hedonic price function (flood discount → CBA & risk management policy)
- RQ: When do behavioral changes matter on macro?

"... and this glorious cliff-top property has recently been reduced by 50%..."

Source: 1 — Bin and Polasky (2004); 2 – Kousky (2010); 3 – Hallstrom, Smith (2005); 4 – Bin and Landry (2013); 5- Pryce, Chen (2011)

III. RHEA: Risks and Hedonics in Empirical Agent-based housing market





- **Theory**: Urban Economics
- **Buyers & Sellers:** location choices; bidding under bounded rationality; memory;
- **Real estate agents:** expectations formation (Hedonic analysis)
- **Data** (Qual & Quant)
  - GIS; Census;
  - Market data (17 years, 2 floods)
  - Semi structured interviews (behavioral rules of traders; sequence of actions; interactions; learning)
- **Auction**

$$\ln Y = \alpha + \sum_i \beta_i x_i + \sum_j \gamma_j z_j + \sum_k \phi_k f_k + \varepsilon$$

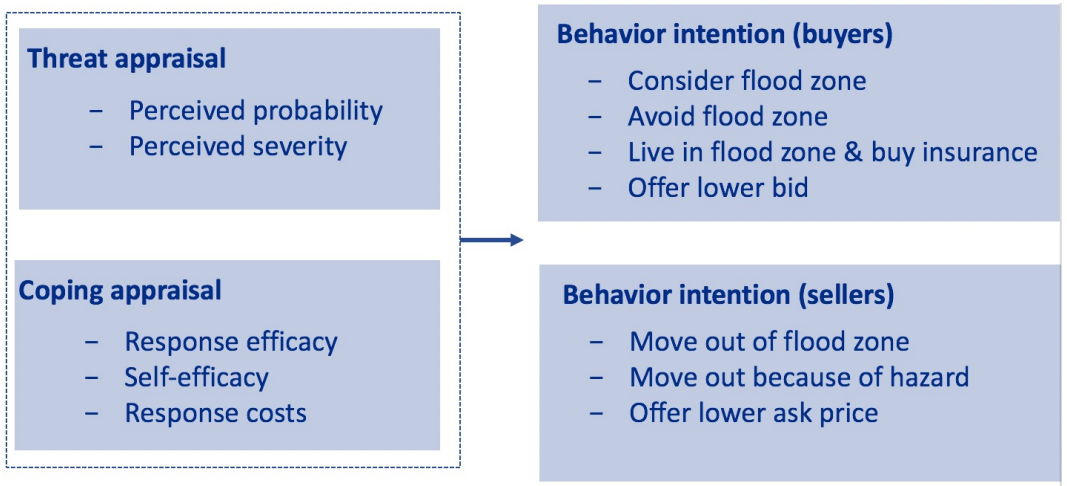
$$\varepsilon = \lambda W \varepsilon + u,$$

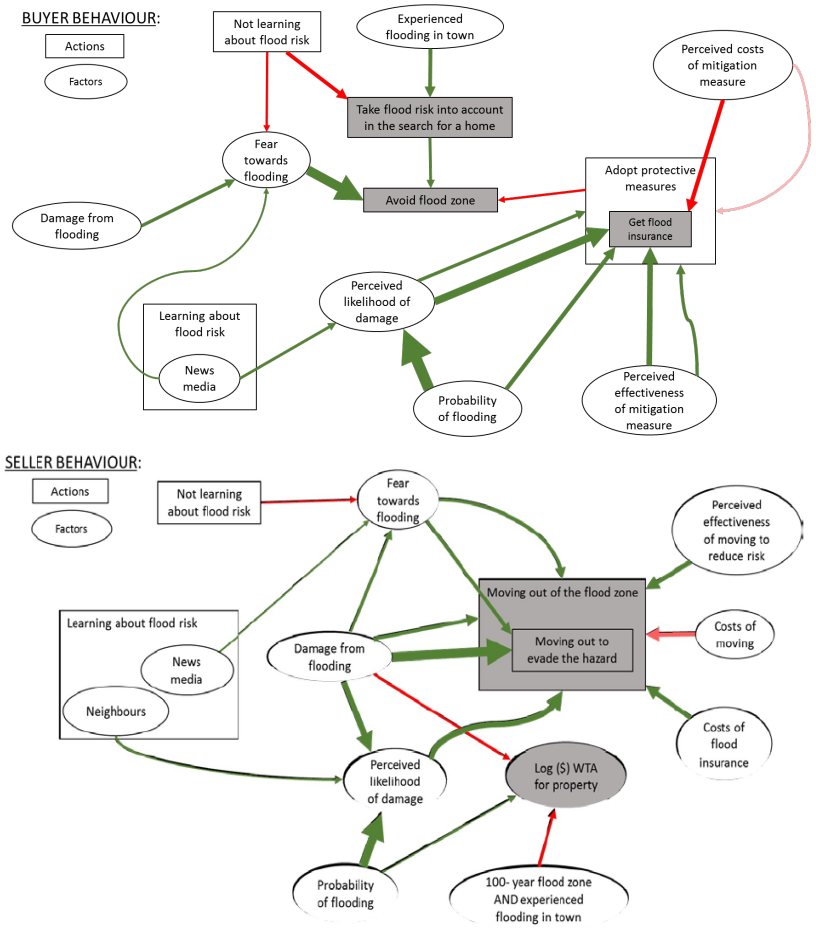
NWO VENI

Source: Filatova (2015) "Empirical agent-based land market: Integrating adaptive economic behavior in urban land-use models", CEUS, 54

III. Behavioral rules: choices under risk & learning

- Household survey[1]:
  - 8 US coastal states in 2018 (after Harvey), N=1040
  - Protection Motivation Theory (Rogers, 1975)
  - Feeling of fear (Slovic, 2004)





- Buyers: effect of fear 4 times stronger than the 'rational' cognitive processes
- Sellers: leave flood zones if experiencing damage (5 times > likely) and fear (2 times)

Effect size for each factor: red -, green +; thickness

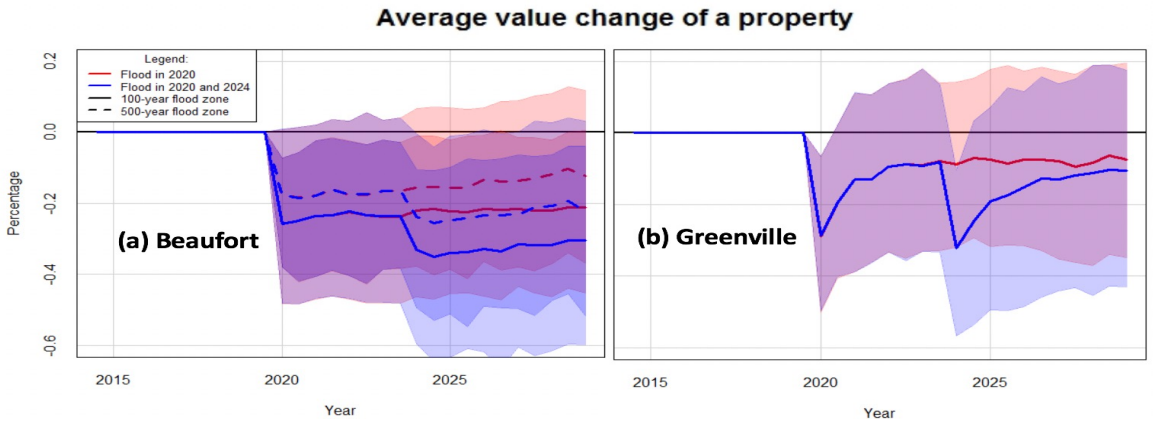
NWO VENI

Source: de Koning et al. (2019) "Avoiding or mitigating flooding: bottom-up drivers of urban resilience …", **Global Environmental Change**

III. Flood-prone housing markets shifting regimes

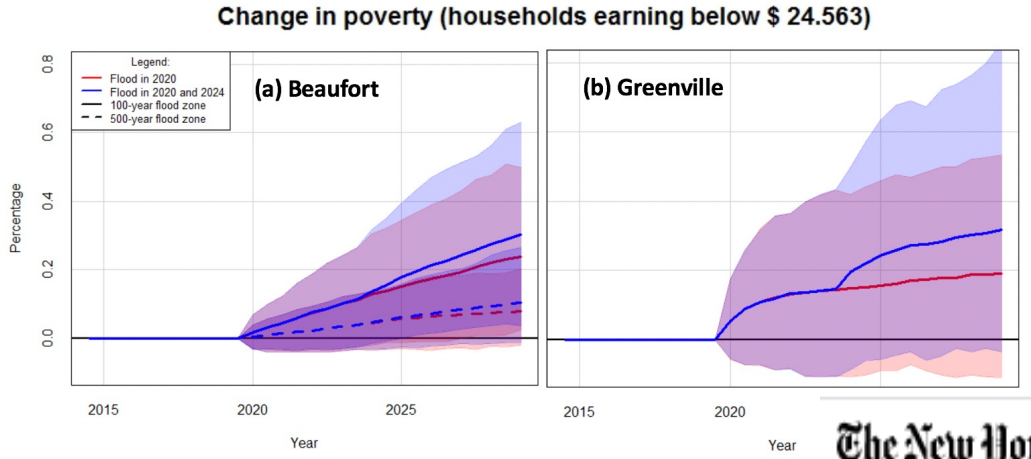
- **Collapse of a local housing market under repetitive hazards**
  - 1 flood vs 2 repetitive floods in 4 years (before memory fades)

& PhD project of Koen de Koning



29.9% in 1:100
21.5% in 1:500 flood-zones;

6.4% in 1:100 flood zones



The New York Times

Florida Sees Signals of a Climate-Driven Housing Crisis

Home sales in areas most vulnerable to sea-level rise began falling around 2013, researchers found. Now, prices are following ward path.

Climate gentrification: the rich can afford to move - what about the poor?

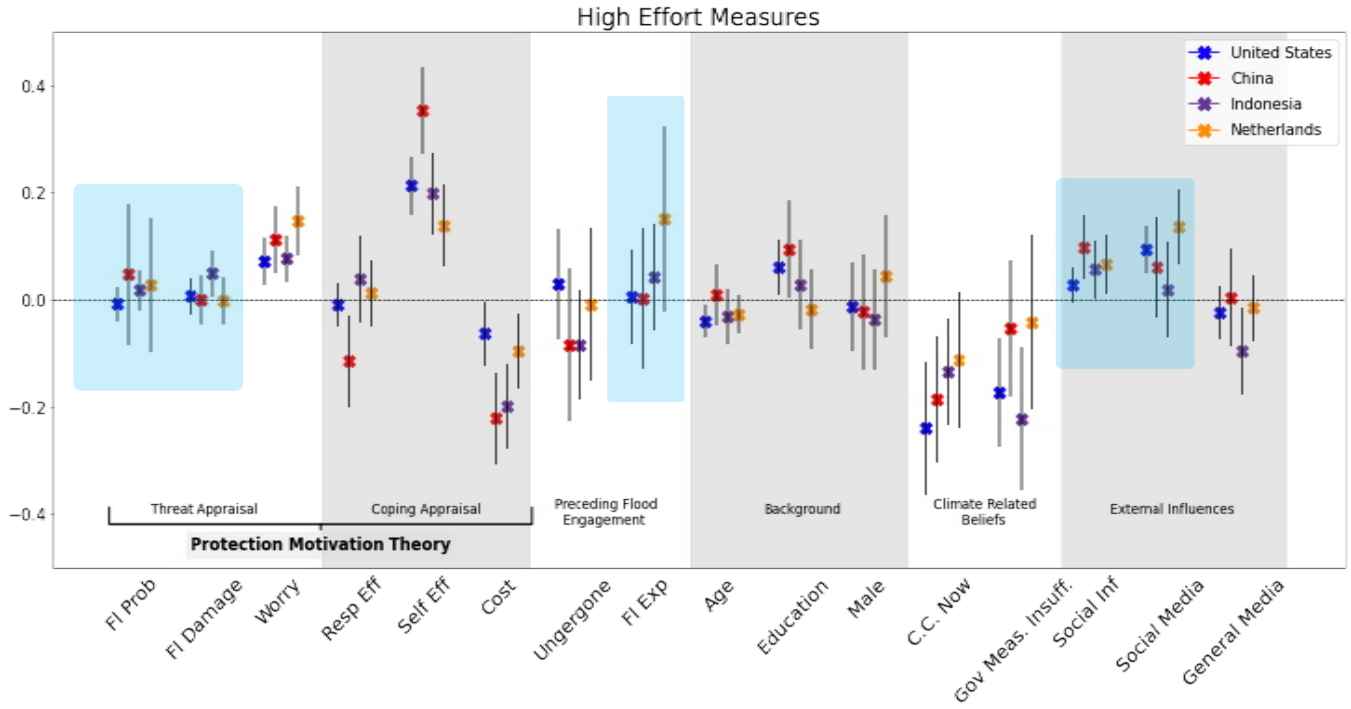
The Guardian

- **Non-marginal structural change:**
  - Market expectations change as fear propagates
  - Low-income households trapped
  - Low-income households are outpriced from safety
  - Path dependency & social segregation

Source: De Koning, Filatova (2020), "Repetitive floods intensify outmigration and climate gentrification in coastal cities", **Environmental Research Letters**

III. Other socio-economic Tipping Elements (CCA)

- **Social Norms** (PhD project Thorid Wagenblast)
  - Social amplification of risk



Effects from Bayesian beta regression models contained in 95% credible intervals

- **Longitudinal Household Surveys (N~6,400)**
  - Protection Motivation Theory
  - Changes in perceptions, social influence, self-assessed resilience
  - Experiencing events; Choice experiments on relocation

Source: Noll et al (2021) "Contextualizing cross-national patterns in household climate change adaptation" **Nature Climate Change**, 1-6

III. Other socio-economic Tipping Elements (CCA)

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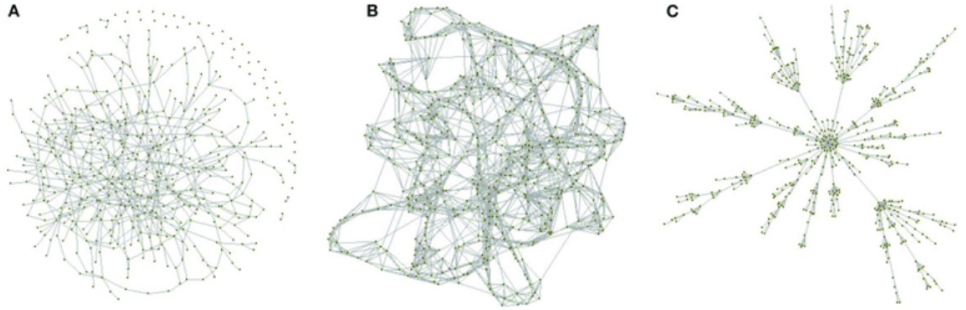
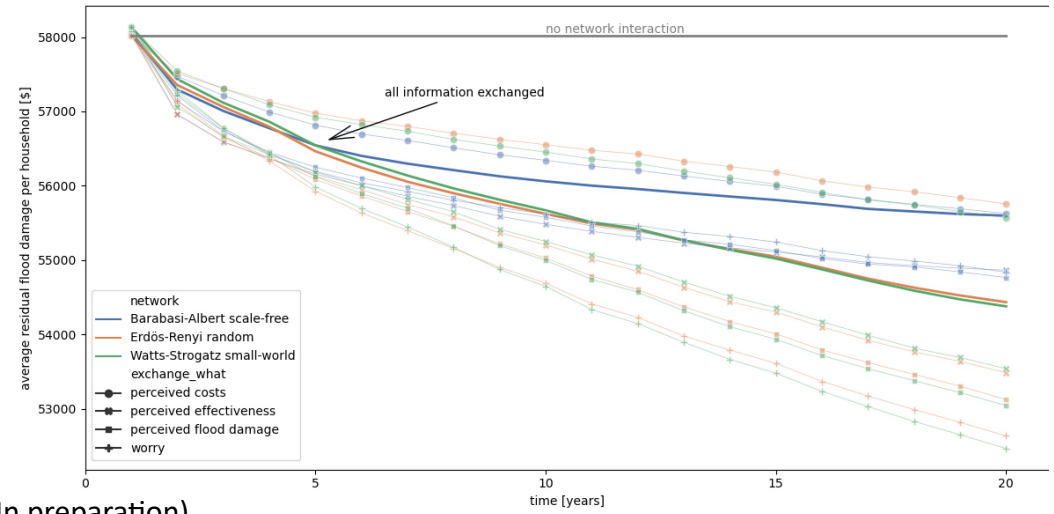
  - Diffusion of adaptation practices



Source: Noll et al (2021) "Contextualizing cross-national patterns in household climate change adaptation" **Nature Climate Change**, 1-6

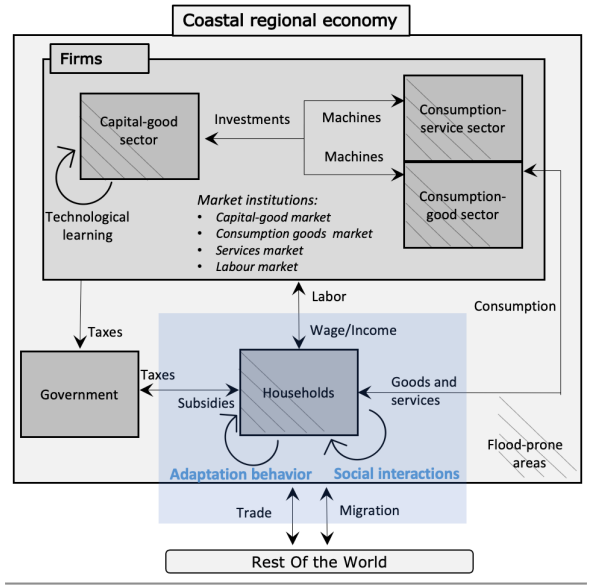
- The 5th wave of the survey: social influence & policy
- ABM & Social Networks
- ABM & Acceptability of policies

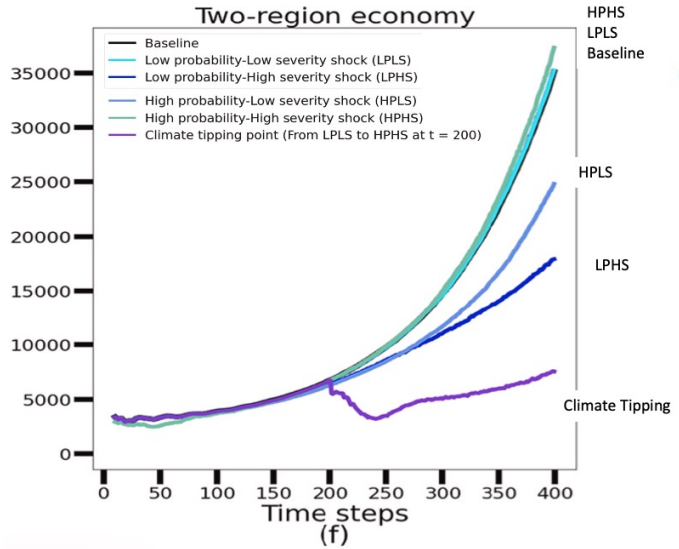


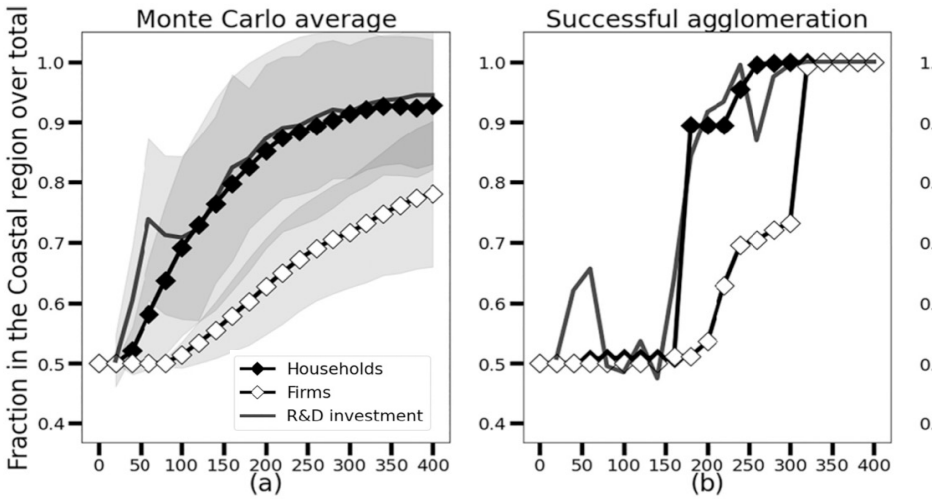
Source: Wagenblast et al (In preparation)

III. Other socio-economic Tipping Elements (CCA)

- **Regional economy** (PhD project Alessandro Taberna)
  - Location of Households & Firms
  - Agglomeration ⇔ Climate change
  - Collapse/Not of a regional economy







Economic tipping leading to a new equilibria

Source: Taberna et al (2022) 'Coping with increasing tides: Evolving agglomeration dynamics…under exacerbating hazards', **Ecological Economics**

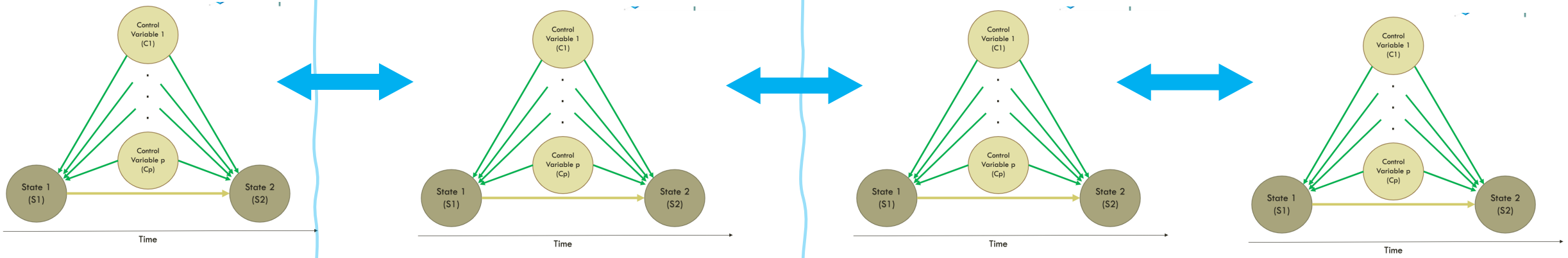
III. Other socio-economic Tipping Elements (CCA)

- **Stranded assets & Finance** (PhD project Joos Akkerman)
  - Climate risk disclosure & stranded assets
    (assets that might unexpectedly devalue prior to their economic lifetime)
  - Damage → Long term slow down of economies
  - Financial systemic risks
    (the risk of an entire financial system/market collapse instead of just its isolated component that is containable without harming the entire system)

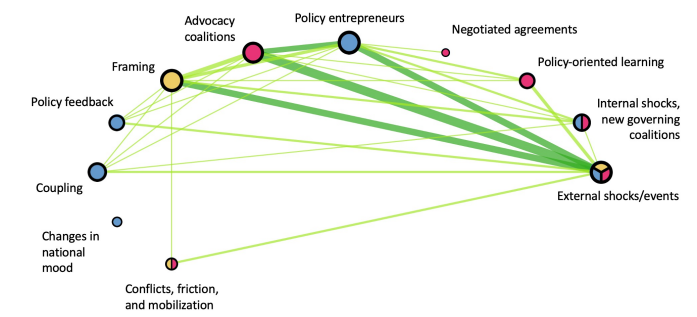
- **Economic & Finance under climate threat** (PhD project Ignasi Corte Arubes)
  - Evolution of Debt to GDP ratio with/without adaptation
  - Dynamics in Credit ranking due to climate imapcts

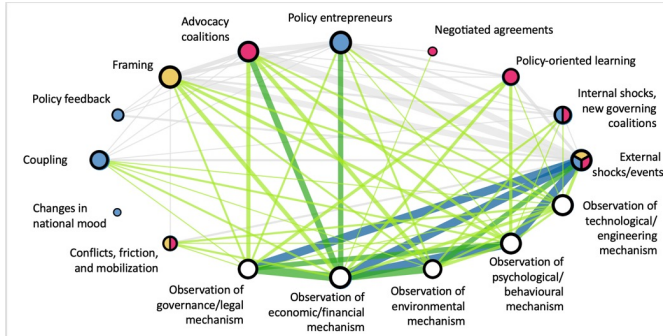
III. Other socio-economic Tipping Elements (CCA)

- **Social Norms**
  (PhD project Thorid Wagenblast)
- **Regional economy**
  (PhD project Alessandro Taberna)
- **Stranded assets &**
  Finance under climate threat
  (PhD projects Joos Akkerman & Ignasi Corte Arubes)



Social Norm 1 | Social Norm 2 | Strengthen dikes | Retreat | Agglomeration at the coast | Agglomeration inland | Thriving market /economy | Collapsed market / economy





IV. Let’s not shy away from modeling socio-economic tipping points

- Work across disciplines to identify relevant Tipping Elements in social systems
- Data: need to “borrow” from non-climate social tipping processes
  as the observation time is too short to find it in the past years/decades
- Mechanisms → Quantifying outcomes space in models that can accommodate bifurcations & other non-marginal change ; Integration of different models / Theories from dif disciplines (mechanisms)
- Mechanisms for social tipping in Mitigation vs Adaptation: same or not?
- Beyond eyeballing & uncertainty ranges alone: clear (statistical) identification of tipping points
- Lessons learned from TP journey in Ecology/ Earth Systems Science, incl. identification, early warning signals